Precision measurement of the proton polarized structure function g^p_1

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Spin Structure Functions at SLAC E142/E143 Experiments

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Precision Measurement of the proton polarized structure function g_1^p

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The E143 collaboration measured the ratio g_1^p/F_1^p over the range $0.029 < x < 0.8$ using deep inelastic scattering of polarized electrons from polarized ammonia. An evaluation of the integral $\int_0^1 g_1^p(x,Q^2)dx$ at fixed $Q^2 = 3(GeV/c)^2$ yields $0.129 \pm 0.004(stat.) \pm 0.009(syst.)$, in agreement with previous experiments, but well below the Ellis-Jaffe sum rule prediction.

Deep inelastic lepton scattering with polarized beam and target is a powerfool tool to study the spin structure of the nucleon by the determination of the proton and neutron polarized structure functions $g_1^{p(n)}$ and $g_2^{p(n)}$. From the integrals $\Gamma_1^{p(n)} = \int_0^1 g_1^{p(n)}(x)dx$ of the structure function g_1 over the Björken scaling variable x, one can test QCD sum rules as predicted by Björken [1] :

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{6}\frac{g_A}{g_V}$$

and by Ellis and Jaffe [2] :

$$\Gamma_1^{p(n)} = \frac{1}{18}[9(6)F - 1(4)D]$$

in the scaling limit. Here g_A and g_V are the nucleon axial and vector coupling constants and F, D are the SU(3) constants measured in hyperon decay. QCD corrections and possibly higher twist corrections must be applied to the above predictions before comparison to the finite Q^2 experiments. Previous measurements of g_1^p [3]-[4] have found Γ_1^p to be below the Ellis-Jaffe sum rule. This has been interpreted to mean that the strange sea and/or the gluons may be significantly polarized, and that the net quark helicity content of the nucleon may be smaller than expected.

The E143 experiment [5] used the SLAC polarized electron beam with energies E of 9.7, 16.2 and 29.1 GeV scattering from polarized proton and deuteron targets in End Station A to measure g_1^p, g_2^p, g_1^d and g_2^d. This paper reports only the g_1^p results at $E = 29.1\ GeV$, covering $1.3 < Q^2 < 10\ (GeV/c)^2$ and $0.029 < x < 0.8$.

The longitudinally polarized electron beam was produced by photoemission from a strained-lattice GaAs crystal illuminated by a flash-lamp-jumped Ti-sapphire laser operated at 850nm [6]. Beam helicity was reversed randomly on a pulse-to-pulse basis. Beam pulses were typically 2 μsec long, contained 2 to 4.10^9 electrons, and were delivered at a rate of 120 Hz. Beam polarization was measured by two Moller polarimeters to a $\pm 4\%$ relative precision and averaged to 85 %.

The targets consisted of solid ammonia NH_3 and deuterated ammonia ND_3. These materials are known to have high resistance to radiation damage. They were polarized using the Dynamic Nuclear Polarization technique : operated at 1 Kelvin in a 5 T magnetic field (oriented parallel or transverse to the beam) and supplied with microwave power at 140 GHz. Target polarization was measured using an NMR system to a $\pm 2.7\%$ relative precision and amounted to 60-80% for NH_3 and 20-40% for ND_3.

Scattered electrons between 6 and 25 GeV were detected in two independent magnetic spectrometers [7] positioned at angles of 4.5° and 7° with respect to the incident beam.

Electrons were distinguished from a background of pions in each spectrometer using two threshold gas Cerenkov counters and a 24-radiation-length shower counter array composed of 200 lead-glass blocks. Seven planes of plastic scintillator hodoscopes were used to measure particle momenta and scattering angles.

Parallel and transverse raw asymmetries are derived for each data set and corrected for all experimental "dilution effects", radiative corrections and nuclear effects. From these physical asymmetries, one then extracts the structure functions g_1/F_1 using the complete formalism of polarized lepton scattering [8], namely not neglecting transverse asymmetries. The values of g_1^p/F_1^p from this experiment at $E = 29.1\ GeV$ are displayed on Figure 1 along with results of previous experiments (SLAC E130 [9] - SMC [4])

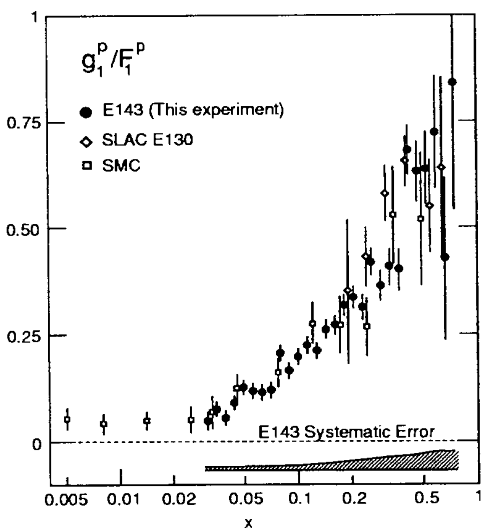

Fig. 1

Figure 1. Ratios g_1^p/F_1^p from this experiment (E143) as a function of x. The errors are statistical only. Systematic errors are indicated by the lower band. The average Q^2 varies from 1.3 $(GeV/c)^2$ at low x to 10 $(GeV/c)^2$ at high x.

Values of xg_1^p at the average $Q^2 = 3(Gev/c)^2$ of this experiment are shown on figure 2. We made the assumption that g_1^p/F_1^p depends only on x [10]. For $F_1^p = (1+\gamma^2)F_2^p/[2x(1+R)]$, we used the NMC fit [11] to F_2^p and the SLAC fit [12] to R.

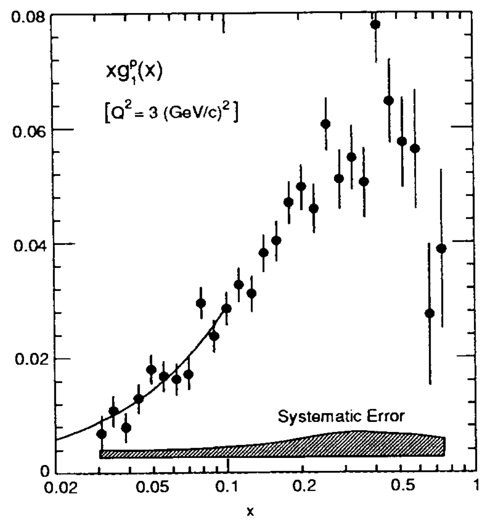

Fig. 2

Figure 2. The structure function g_2^p (scaled by x) from this experiment evaluated at fixed $Q^2 = 3\ (GeV/c)^2$. The systematic errors are indicated by the lower band. The curve is given by $g_1 = 0.29$, the value used for the low x extrapolation.

An extrapolation from $x = 0.8$ to 1 was done assuming g_1 is proportionnal to $(1-x)^3$ at high x. At low x, we studied the x-dependence of g_1^p using data combined with SMC and EMC data. We observe that, consistent with Regge theory [13], all data for $x < x_{max} = 0.1$ are well-fit (χ^2/d.f.=0.9) by a constant value of $g_1^p = 0.29 \pm 0.02$ at $Q^2 = 3$ $(GeV/c)^2$.

Given the two assumptions that g_1/F_1 depends only on x and that g_1^p is constant at low x, we obtain the total integral $\Gamma_1^p = 0.129 \pm 0.004 \pm$

0.009. This is in good agreement with the value from SMC [4] asymmetries, $\Gamma_1^p = 0.122 \pm 0.011 \pm 0.011$, obtained at $Q^2 = 3$ $(\mathrm{GeV/c})^2$ assuming $g_1/F_1 \approx A_1$ is independent of Q^2. Our result is more than two standard deviations below the Ellis-Jaffe sum rule prediction of 0.160 ± 0.006, evaluated using the QCD corrections of Ref. [14] with $\alpha_s = 0.35 \pm 0.05$ at $Q^2 = 3$ $(\mathrm{GeV/c})^2$.

We can use the quark parton model and the SU(3) coupling constants $F+D = 1.2573 \pm 0.0028$ and $F/D = 0.575 \pm 0.016$ [17] to extract the total quark contribution to the proton helicity $\Delta q = \Delta u + \Delta d + \Delta s = 0.29 \pm 0.10$, which is small compared to the Ellis-Jaffe prediction $3F - D \approx 0.58$ for $\Delta s = 0$.

The combined analysis of all the existing proton and neutron data show that they are consistent with each other and agree within 10% with the Björken sum rule. Quark spins account for only about 30% of the nucleon spin. To understand the spin structure of the proton, one has to take into account an unexpectedly large effect of either the gluon spins or the orbital angular momentum of quarks and gluons.

At SLAC, two new experiments E154 and E155 are planned to measure the proton, deuteron and Helium 3 spin structure functions with a 50 GeV electron beam in fall 1995. By this time, SMC will have additionnal data on proton and deuteron and HERMES will be running on HERA ring. These new results will allow a better knowledge of the Q^2 dependence of the structure functions. The next major experimental step will be the measurement of the gluon contribution ΔG to the nucleon spin [15].

Recent papers [16] discuss the validity of the assumption that g_1 is approximately constant as $x \to 0$. The only experimental facility where small x behavior of g_1 could be tested is HERA with polarized protons and electrons. Electron polarization already available will be used by the HERMES collaboration with a high purity polarized atomic gas target. If the protons can be polarized too, a whole new field of experiments will be open to study nucleon spin.

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